Oscillations of the Atmospheric Dynamic State in Simulations of LP 890-9 c

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Through the identification and characterization of exoplanet atmospheres, we will soon begin to truly understand the evolution and habitbility of extrasolar terrestrial planets. Due to their long main-sequence lifetimes and relatively low luminosities, planets orbiting M dwarf stars are the focus of these searches. Delrez et al. (2022) identified a planet, LP 890-9 c orbiting a faint M6 star. Both LP 890-9 c and the inner planet LP 890-9 b are likely rocky, with radii of $\approx 1.3\,R_\oplus$. Planet b is well inward of the classical habitable zone (HZ), although LP 890-9 c has an instellation of $0.906\,S_\oplus$–placing it near the inner edge of the HZ. Our limited understanding of the co-evolution of rocky planets and M dwarf host stars make LP 890-9 c an ideal subject to test the possible climatic outcomes for the inner edge of the HZ such stars.

Simulations of Earth-like exoplanets have shown that at least three circulation regimes are possible on synchronously rotating planets (e.g., Merlis & Schneider, 2010; Carone et al., 2015; Haqq-Misra et al., 2018). Here, we report on the discovery of periodic oscillations between these previously identified dynamic regimes in simulations of LP 890-9 cusing the ROCKE-3D general circulation model (Way et al., 2017). The two regimes are: one with a single dominant equatorial superrotating jet, and another with two superrotating jets at midlatitudes. We present the results from a limited parameter study that includes an initial six simulations of LP 890-9 c and an additional four follow-up simulations. We find that 3 out of 6 of our original simulations display atmospheric regime oscillations. These simulations use a fully-coupled dynamic ocean model and we vary greenhouse gas concentrations and rotation rate. Our follow-up simulations use a q-flux (slab) ocean model and show no oscillations although display atmospheric bistability similar to Edson et al. (2011) or Sergeev et al. (2022). Fig. 1 shows the zonal velocity for the two regimes in our `CONTROL` simulation. The oscillations take place over a period of ≈ 112 Earth years, with most of the time being spent in single jet regime. The atmospheric dynamic state can impact the mean surface temperature, fractional habitability, and cloud distribution. Given the uncertainties in modeling and observations it is not clear the likelihood that LP 890-9 c 's atmosphere oscillates as seen in these simulations, if it has one at all. Despite this, our discovery represents a fascinating new addition to our understanding of atmospheric dynamics around tidally-locked terrestrial planets in M-dwarf systems. Furthermore, these results highlight the importance of ocean heat transport and dynamics in modeling the atmospheres of Earth-like exoplanets and should be included in future studies.

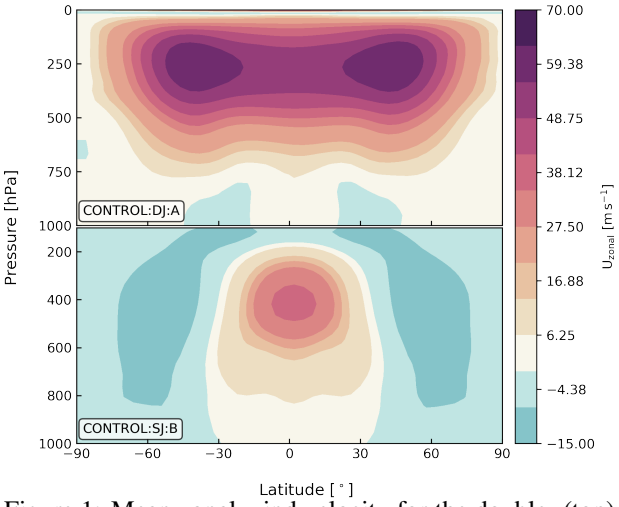

Figure 1: Mean zonal wind velocity for the double- (top) and single-jet (bottom) regimes in our `CONTROL` aquaplanet simulation. Velocities have been averages over 5 and 10 yrs, respectively.

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